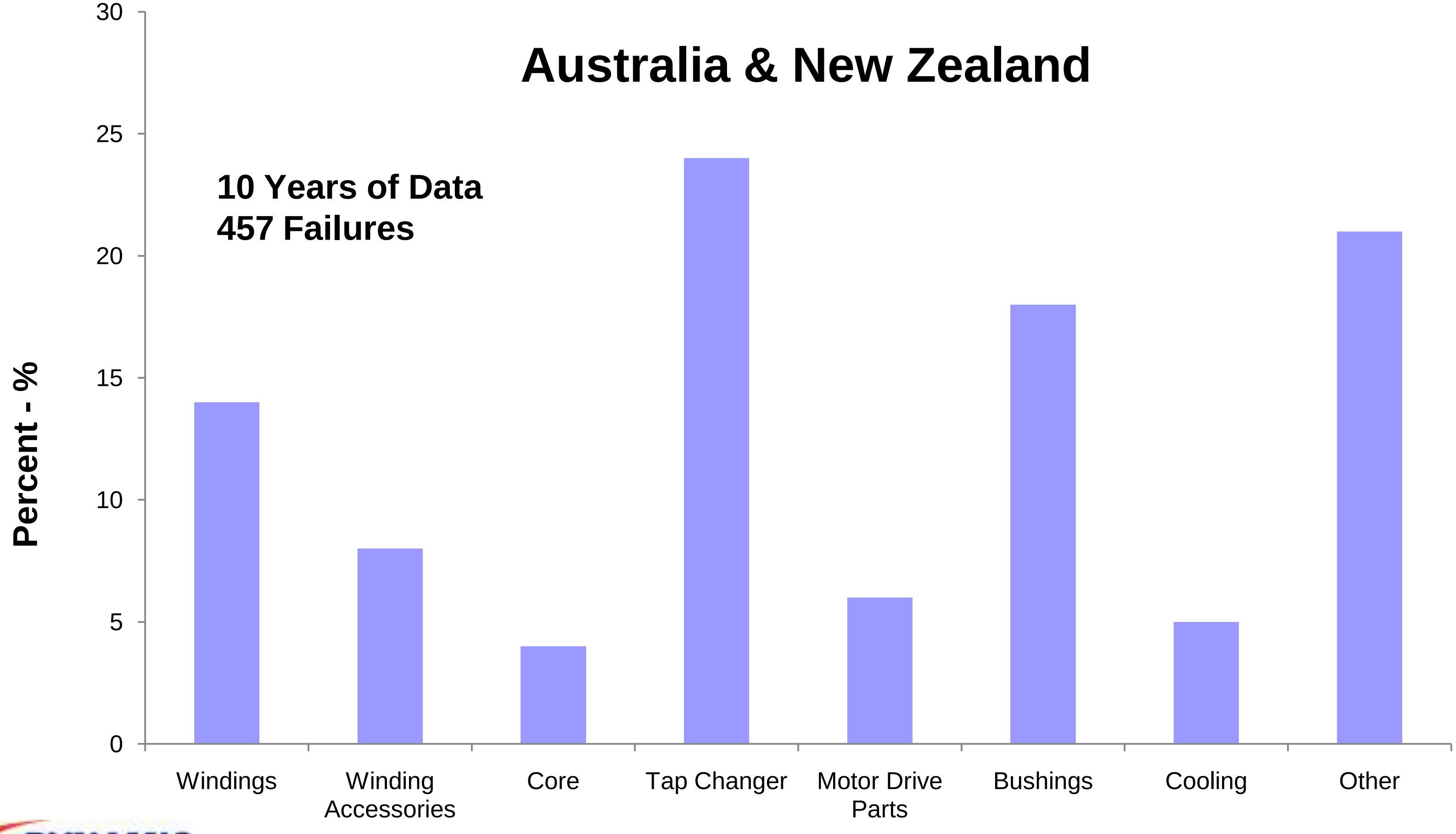
On-line PD Monitoring Applications

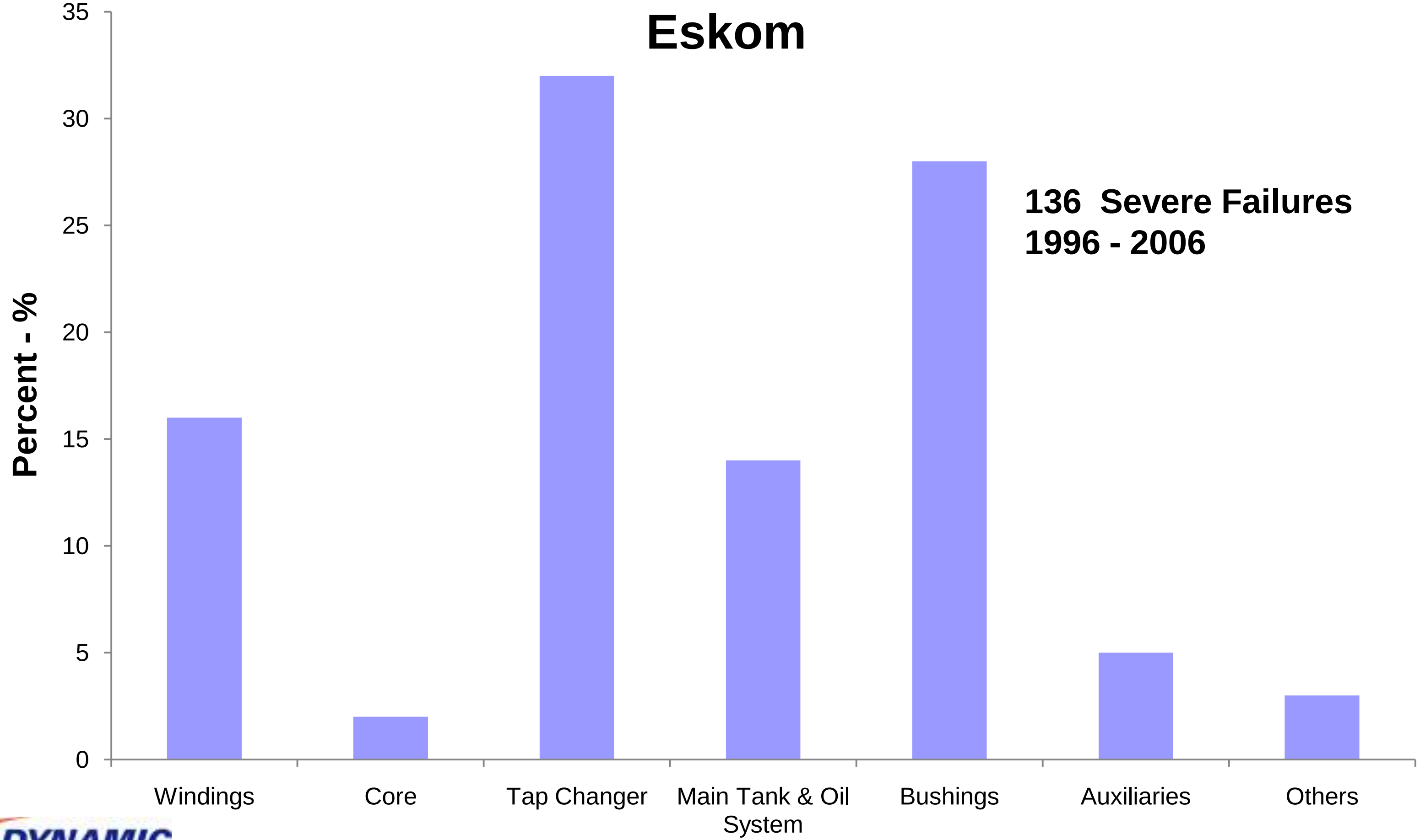
Motors
Generators
Switchgear
Cables
Transformers

DYNAMIC RATINGS

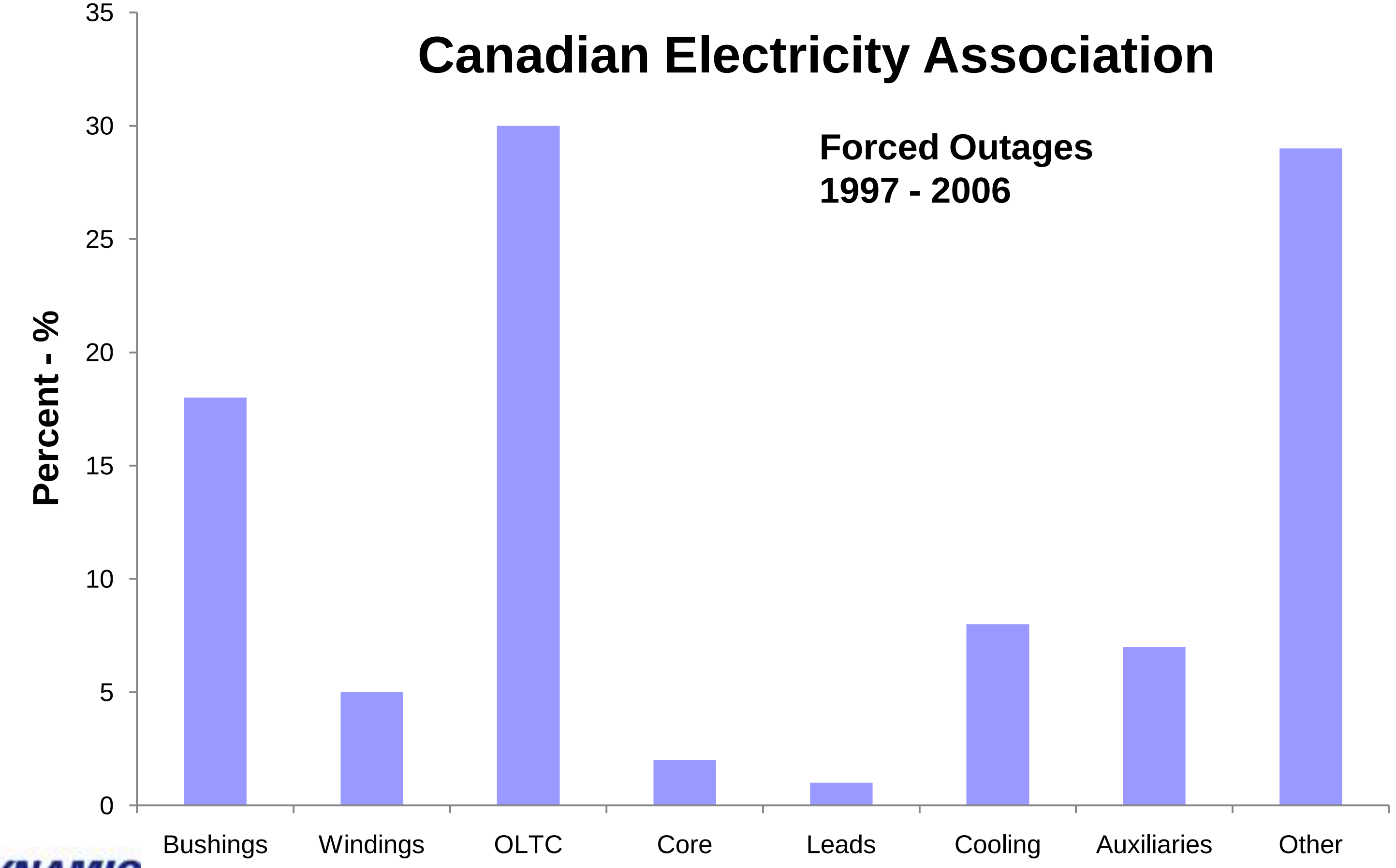
Failure Statistics



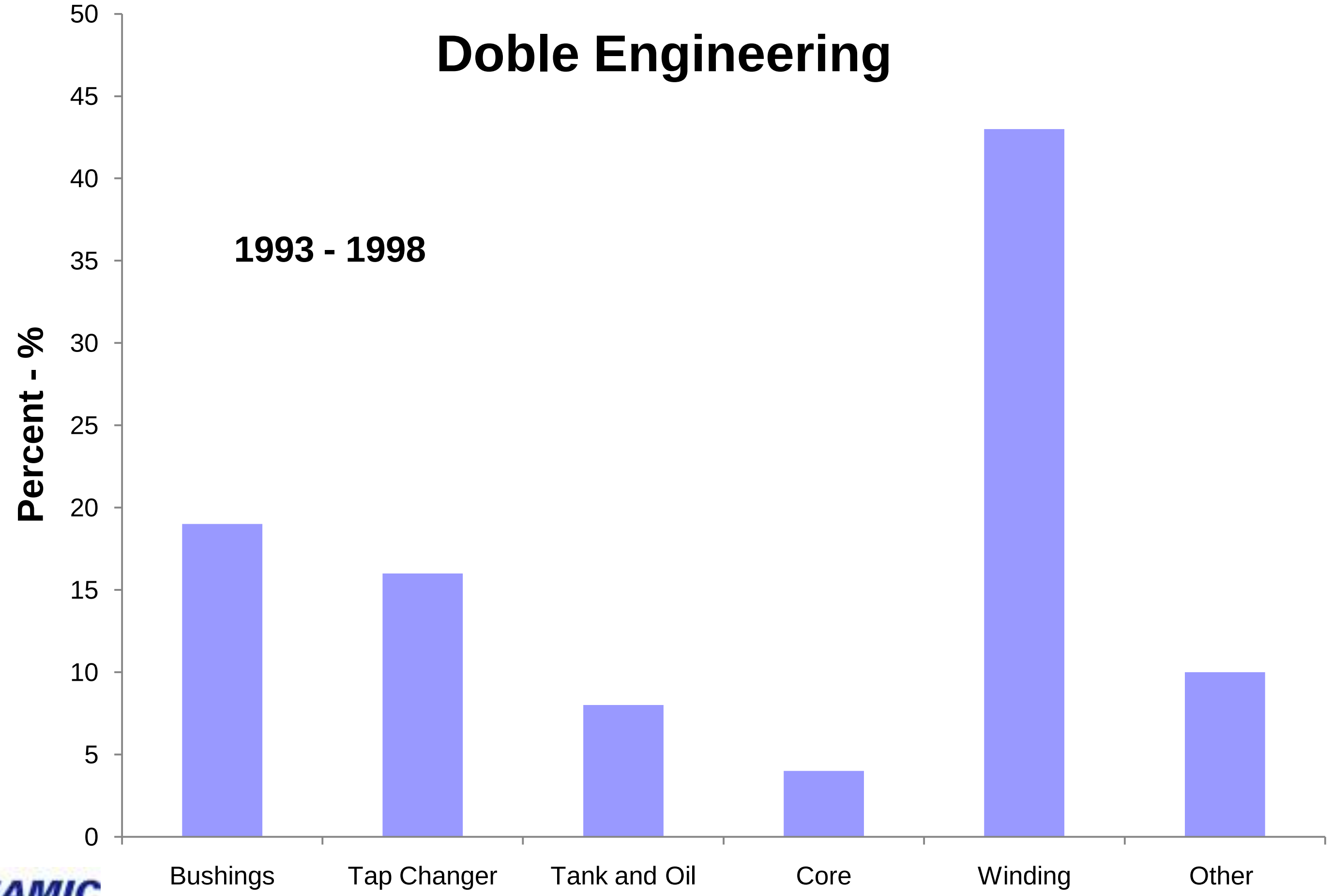
Failure Statistics



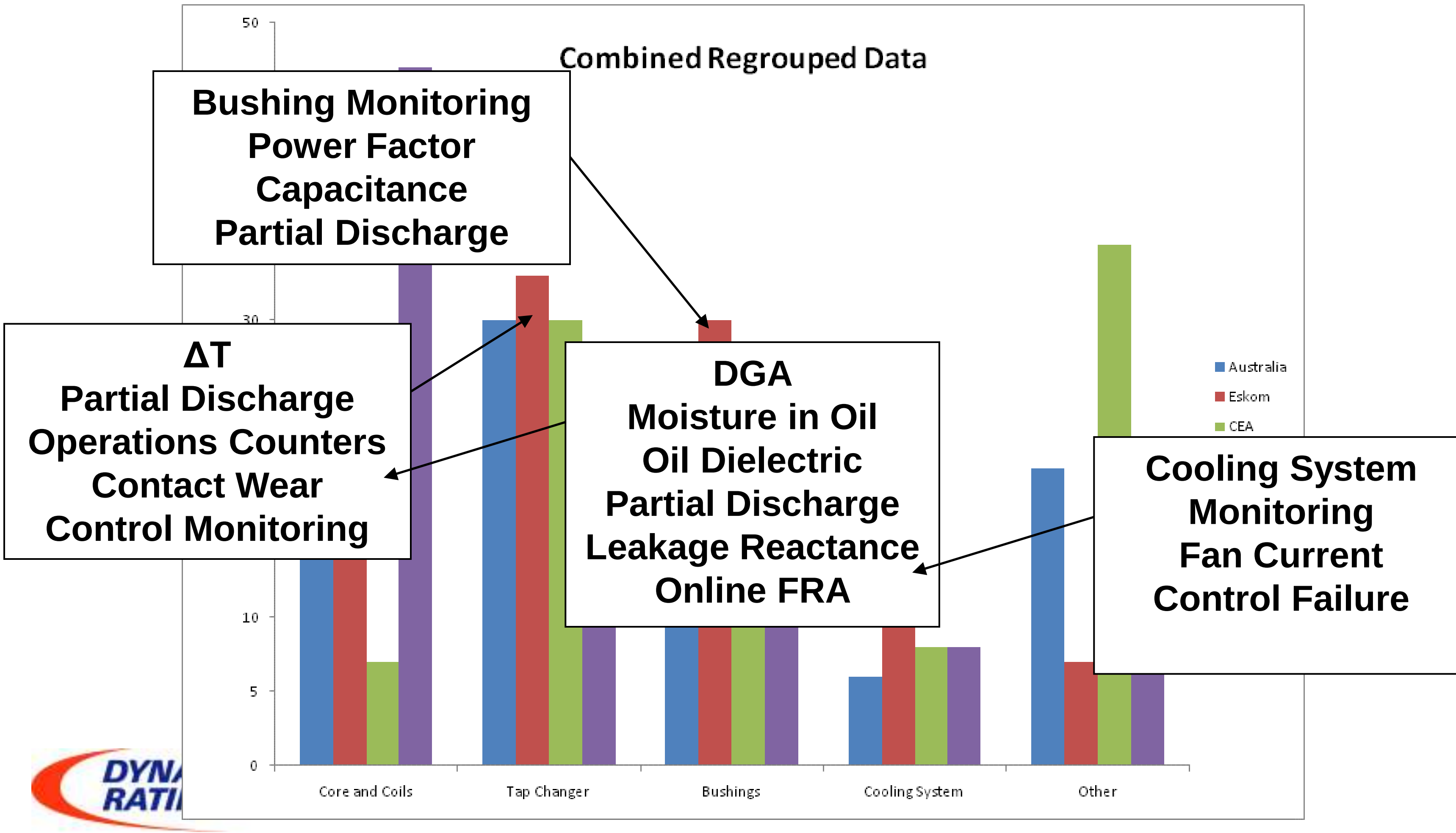
Failure Statistics



Failure Statistics



Failure Statistics



Issues With Time Based Maintenance

- Time between outages extended
- Many failure modes happen quickly (days, weeks, months)
- Off-line tests can not simulate actual operating conditions (temperature, voltage, load, mechanical)
- Historical data not sufficient to make a good decision
- Less thorough maintenance
- Can introduce new failure mechanisms

DYNAMIC RATINGS

Time to Failure

- Very Difficult to Predict / Forecast
- Studies have shown
  - 80% of all failures are random in nature
  - 20% age related
- If this is true, then current maintenance practices are not all that effective

DYNAMIC RATINGS

Time To Failure

- Good Bill of Health
  - Only means there is no clue as to the unit will fail
- Easier to Predict when Failure is imminent
  - Advanced stages of deterioration
- The only true way to capture impending failure is to monitor continuously

Transformer Bushing Monitoring

Bushing failure statistics

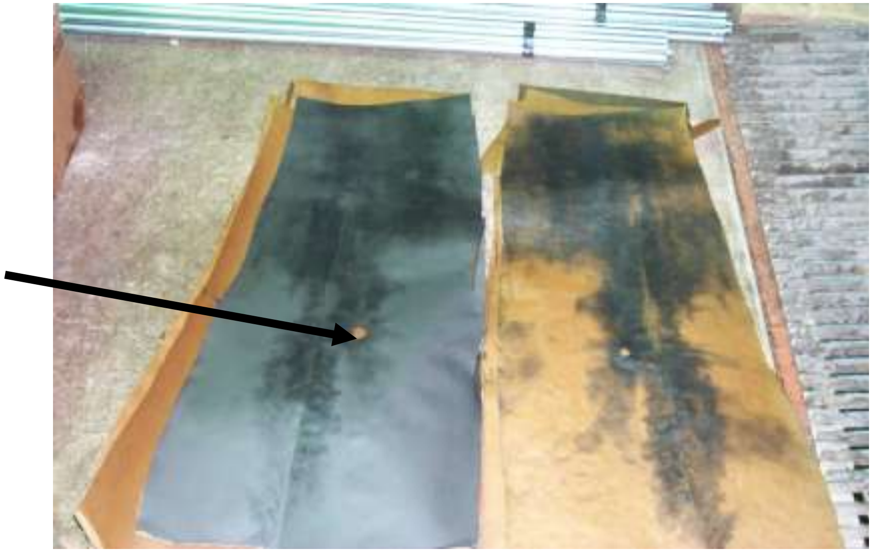
Change in C1 Power Factor/Capacitance	53.0%
Change in C2 Power Factor	7.4%
Service Advisory	3.4%
Problems with Taps	2.8%
Moisture Ingress	2.8%
Infra-Red Scan	1.9%
Partial Discharge	1.4%
Other	27.3%

Violent	**52.3%**
Non-violent	**47.7%**

DYNAMIC RATINGS

Facts

- Bushing Failed in June 2001
- Passed Doble testing in Oct 1998
- Investigation confirmed a dielectric failure with a paper insulation puncture through the center draw rod area
  - About 1/3 of the way down from the top terminal

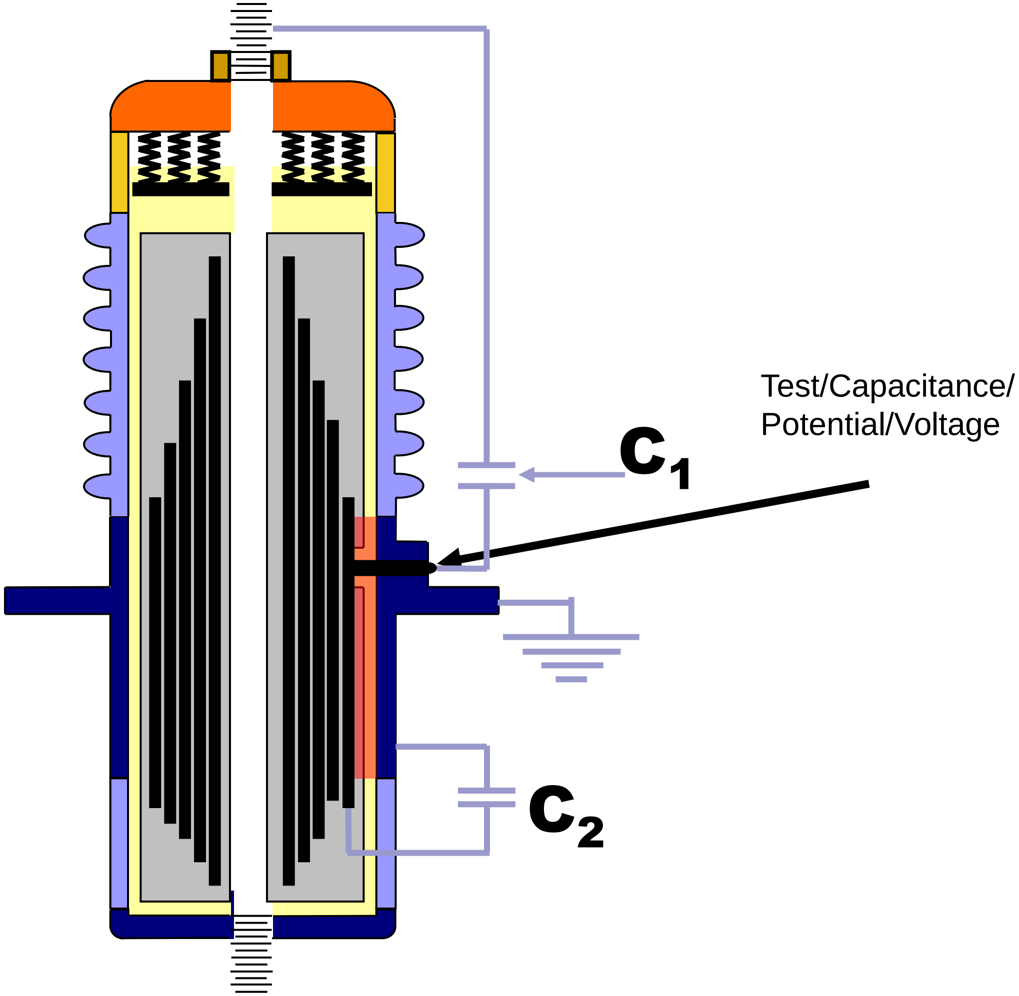


Photos furnished by BC Hydro

DYNAMIC RATINGS

Two Capacitances

- C1
- C2
- C1 can be measured On Line



Sensor connects to bushing tap

DYNAMIC RATINGS

Transformer Partial Discharge Monitoring

What is Partial Discharge?

- PD is a leading indicator of insulation breakdown.
- The higher the voltage the more destructive the activity.
- Phenomena that only occurs at higher AC voltages (> 2,000 V). Prefer 3 kV and higher.

DYNAMIC RATINGS

Definition - PD

Spark

A Localized Electrical Discharge in an Insulation System that does not completely bridge the Electrodes.

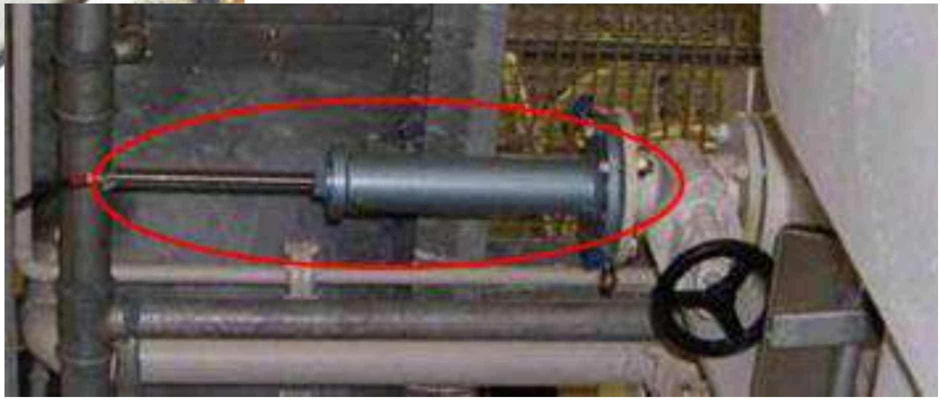
Phase to Phase

Phase to Ground

Acoustic Sensors

DYNAMIC RATINGS

UHF Type of Sensors



DYNAMIC RATINGS

Direct electrical

Key Element on Direct Connection - Bushing Protection

- Bushing are normally grounded at the tap.
- When monitoring, the bushing are now grounded at the instrumentation
- If ground connection is lost or wire is cut, this can cause a large voltage to build up at the tap and cause a failure

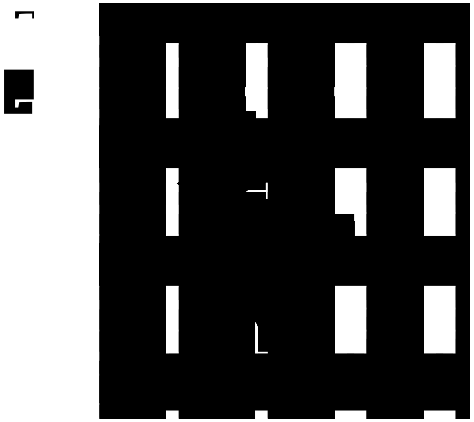
Not All Bushing Sensors are Equal

- Basically two common types of Sensors
  - Capacitive
  - Resistive
- Protection Elements to Consider
  - Surge Protection
  - Open Circuit protection
  - Possible Fail Safe Circuit

DYNAMIC RATINGS

PD Pulse Characteristics

- Generates a High frequency Pulse
  - Rise Time 1 nS to tens of nS
  - Pulse width 1 nS to few hundred nS
  - Frequency Range 0 – 10’s of GHz
  - Usually measured in pC or mV

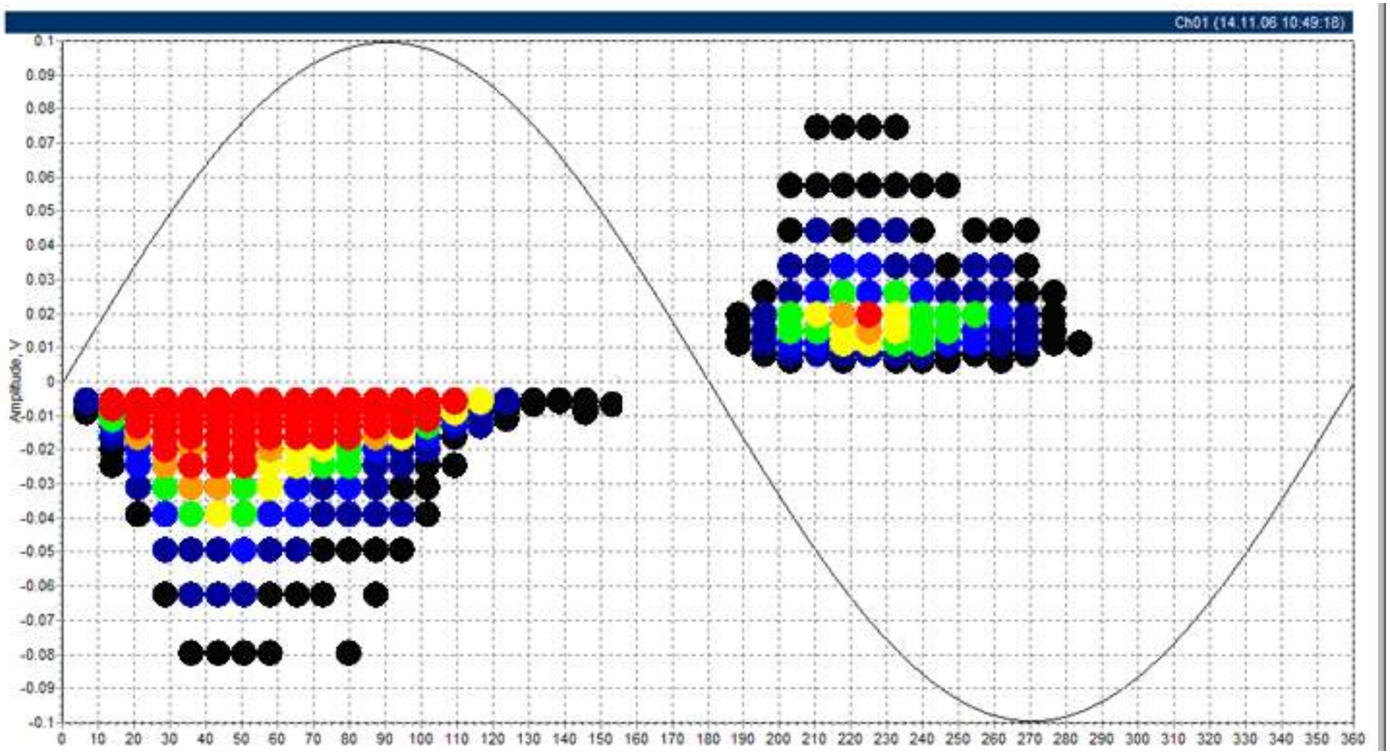


PD Quantities

- PD Magnitude (mV or pC)
  - Size or the volume of the defect
- Pulse Count (PPS)
  - Number or Growth of defects
- PD Intensity/Power (mW)
  - Destructive Power of the PD events
- PD Signature
  - Phase of the Defect
  - Type of Defect

DYNAMIC RATINGS

Phase Resolved Data



- Phase to Ground
- Phase to Phase
- PD Signature



Two methods of PD detection

Method	Pros	Cons
Acoustic Piezo accelerometer on tank	■Easy to install – External on tank ■Most common on Transformers today ■Usually can get pulse repetition rate and trend ■Not susceptible to external electrical noise ■Possible location of defect	■Low Sensitivity ■Depends where defect is located and internal design of transformer ■Does respond to rain, sleet and other possible disturbances ■Very Time Consuming
Electrical Sensor connected to bushing taps Additional sensors on ground wire, other locations	■High sensitivity ■Can be calibrated in terms of apparent charge ■Approximate location of PD source ■Use of pattern/signature recognition	■Need Outage to install sensors ■Sensitive to external electrical noise

DYNAMIC RATINGS

PD/sparking in transformers

- Will produce gases
- How fast?
  - Depends on size & type of defect
  - Location of defect
  - Temperature at defect
  - Volume of oil
  - Transformer design
- Will range from days to …..

DYNAMIC RATINGS

pC levels for insulation

	pC
Defect Free	10 - 50
Normal deterioration	< 300 - 500
Developing Defects (Irreversible damage to paper)	1,000 – 3,000
Breakdown of Oil Gap	10,000 – 100,000

DYNAMIC RATINGS

Example of discharge on transformer barrier

Creeping discharge
within
Pressboard barrier

Discharge in excess of

10,000 pC

DYNAMIC RATINGS

External Noise

- Especially on Transformers
  - Floating Potentials
    - Loose bus Insulators
    - Sparking Static Shields
  - Loose Ground connections
  - Radio Transmissions
  - Corona
- Cross Coupled Signals

DYNAMIC RATINGS

Noise Cancellation

- This is a key item for in-field / continuous monitoring measurements
- Factories can control noise
- Can not do that in the Field
  - Corona
  - Loose support insulators
  - Radio Stations,
  - Etc.

DYNAMIC RATINGS

Noise Cancellation Methods

- Pulse Shape Analysis
- Gating
- Notch Filters
- Pulse Direction
- Pulse Patterns

Pulse Direction is Key

- One needs to determine if the measured signal is coming from
  - Inside the transformer
  - External to the transformer.
- Allows this to be an active system
  - Conditions change

DYNAMIC RATINGS

Noise Cancellation

- Time of arrival
- Compares Time of Pulses to reach instrument

Pulse Polarity

- Pulse Polarity (To determine direction)
  - Uses two types of Sensors
    - One Capacitive
    - One Inductive

DYNAMIC RATINGS

Pulse Polarity Very Practical Solution

- Bushing Sensor – Capacitive Element

- Rogowski Coil – Inductive Element

DYNAMIC RATINGS

Pulse Direction Determination

DYNAMIC RATINGS

Case Study 1

- 500 kV – 230 kV, 3 phase transformer
- No Outage
- Only RFCTs on neutral connection and tank ground

DYNAMIC RATINGS

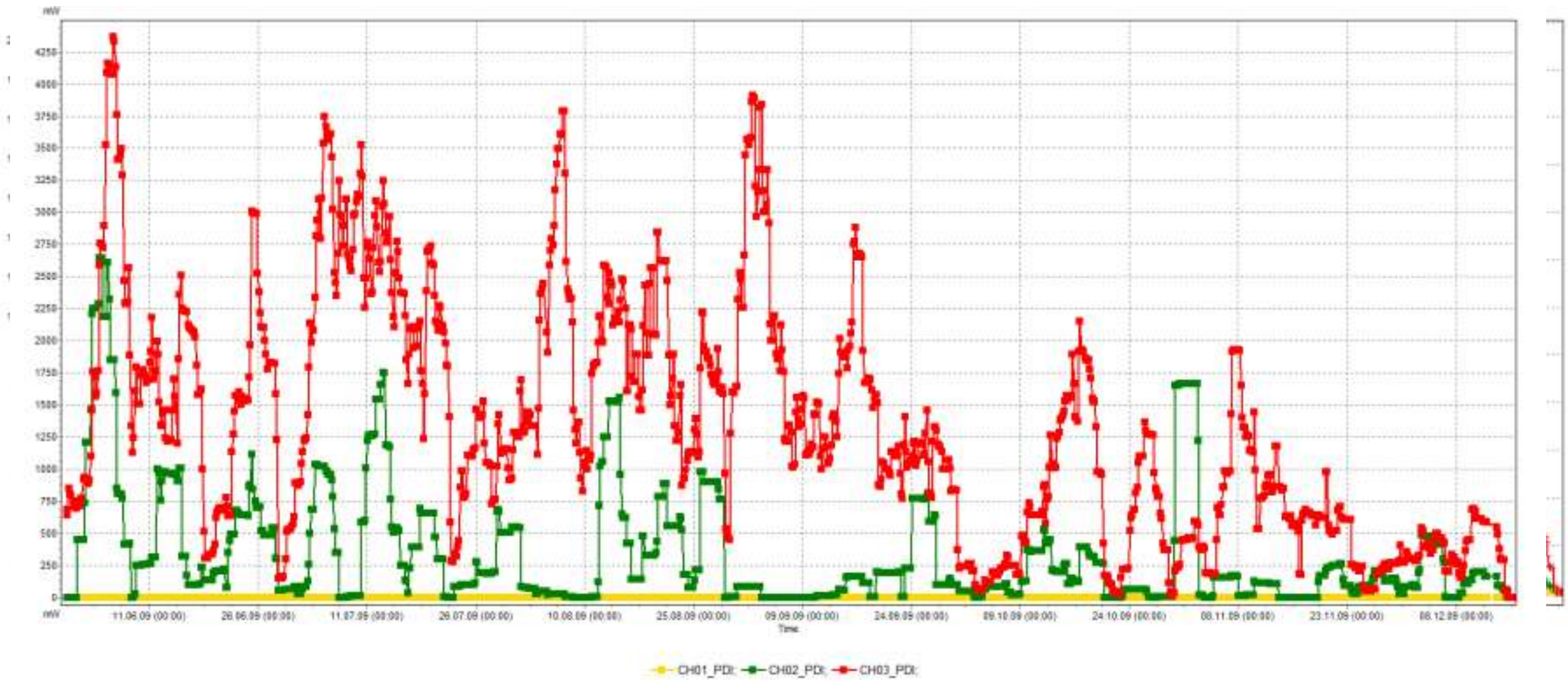
Case Study 2

- 500 kV - 3 phase tank
- 6 bushing sensors
- 6 Rogowski Coils
- RFCT on Neutral
- Bushing Monitoring
- PD Monitoring

DYNAMIC RATINGS

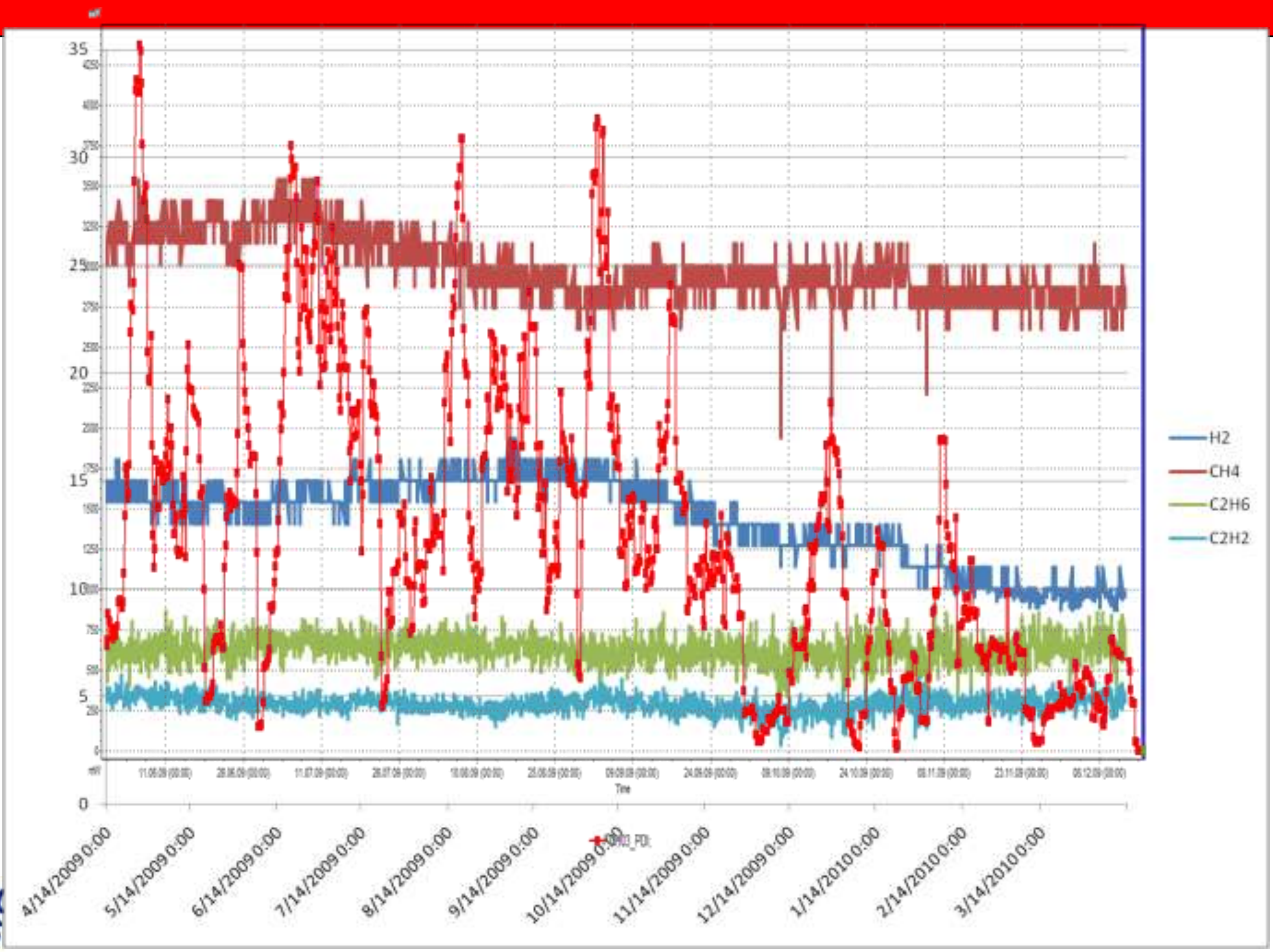
Case 2 Installation

PD Trends



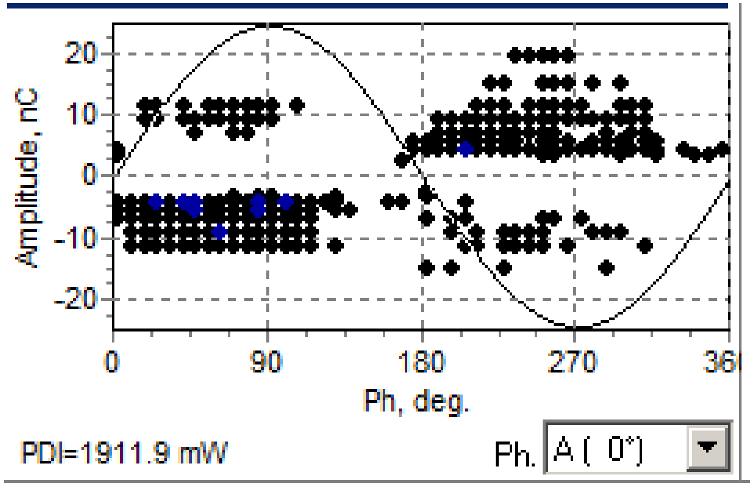
DYNAMIC RATINGS

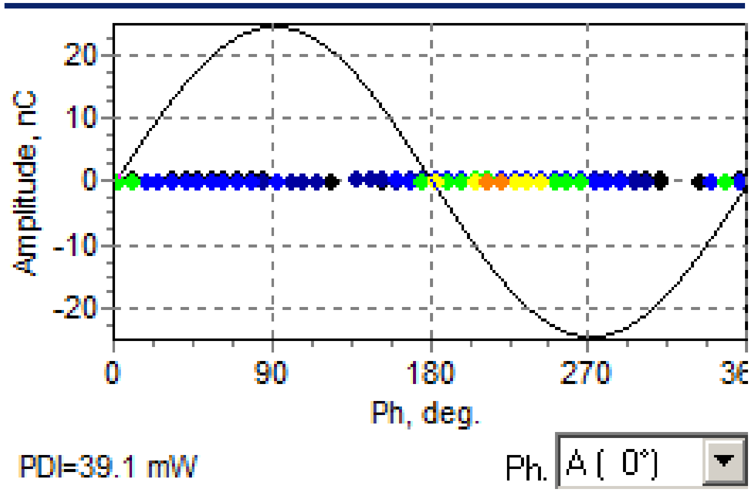
DGA Results



DYNAMIC RATINGS

Case 2 Phase Resolved Data

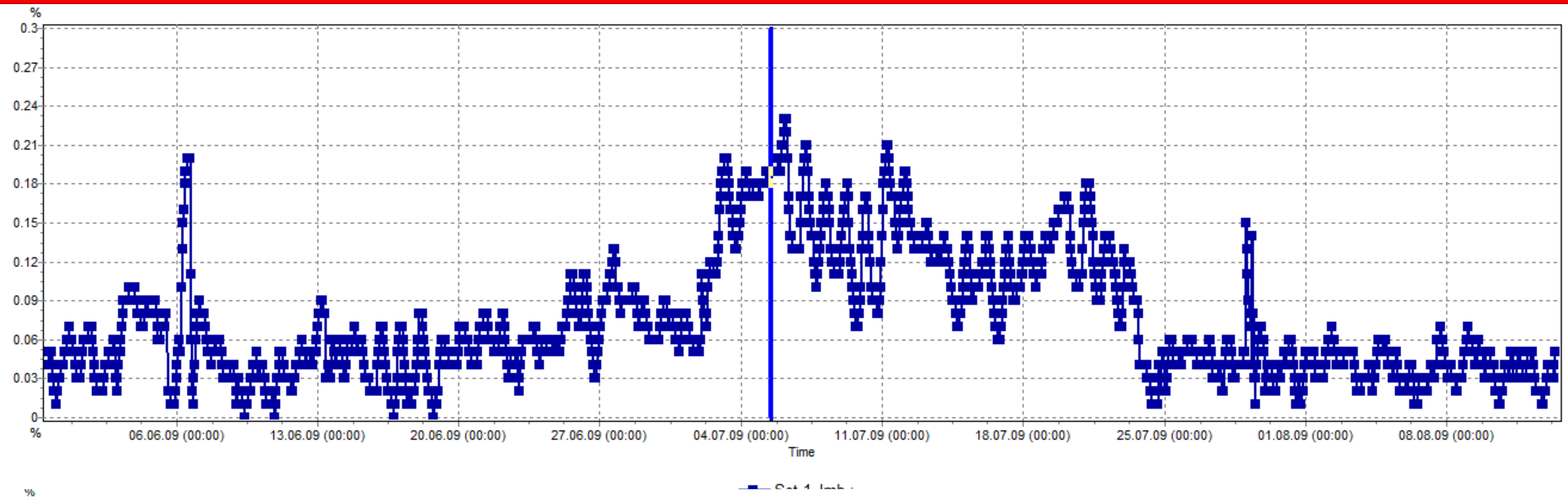


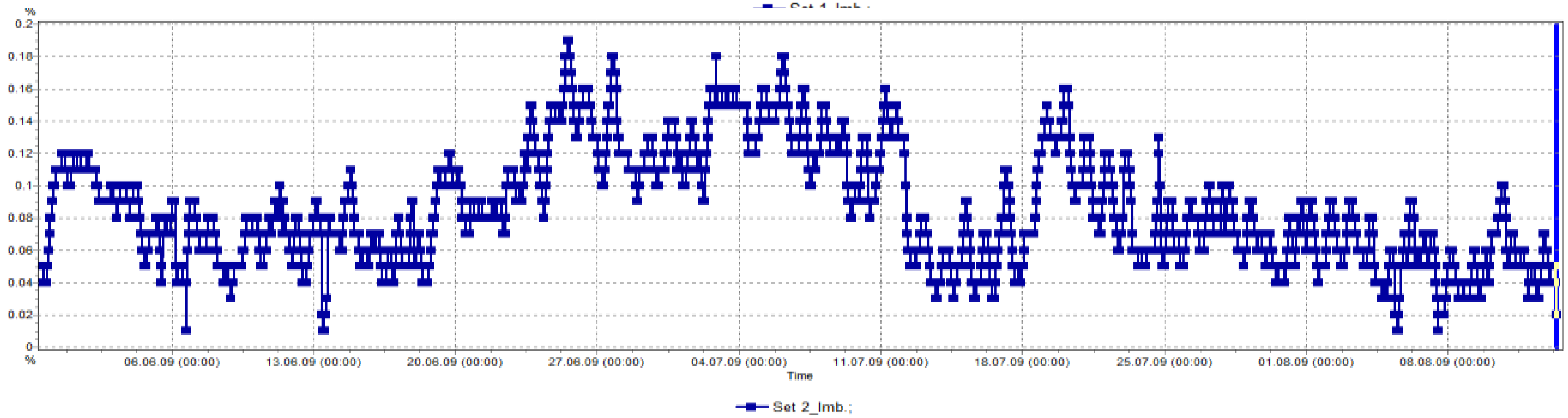


Signal

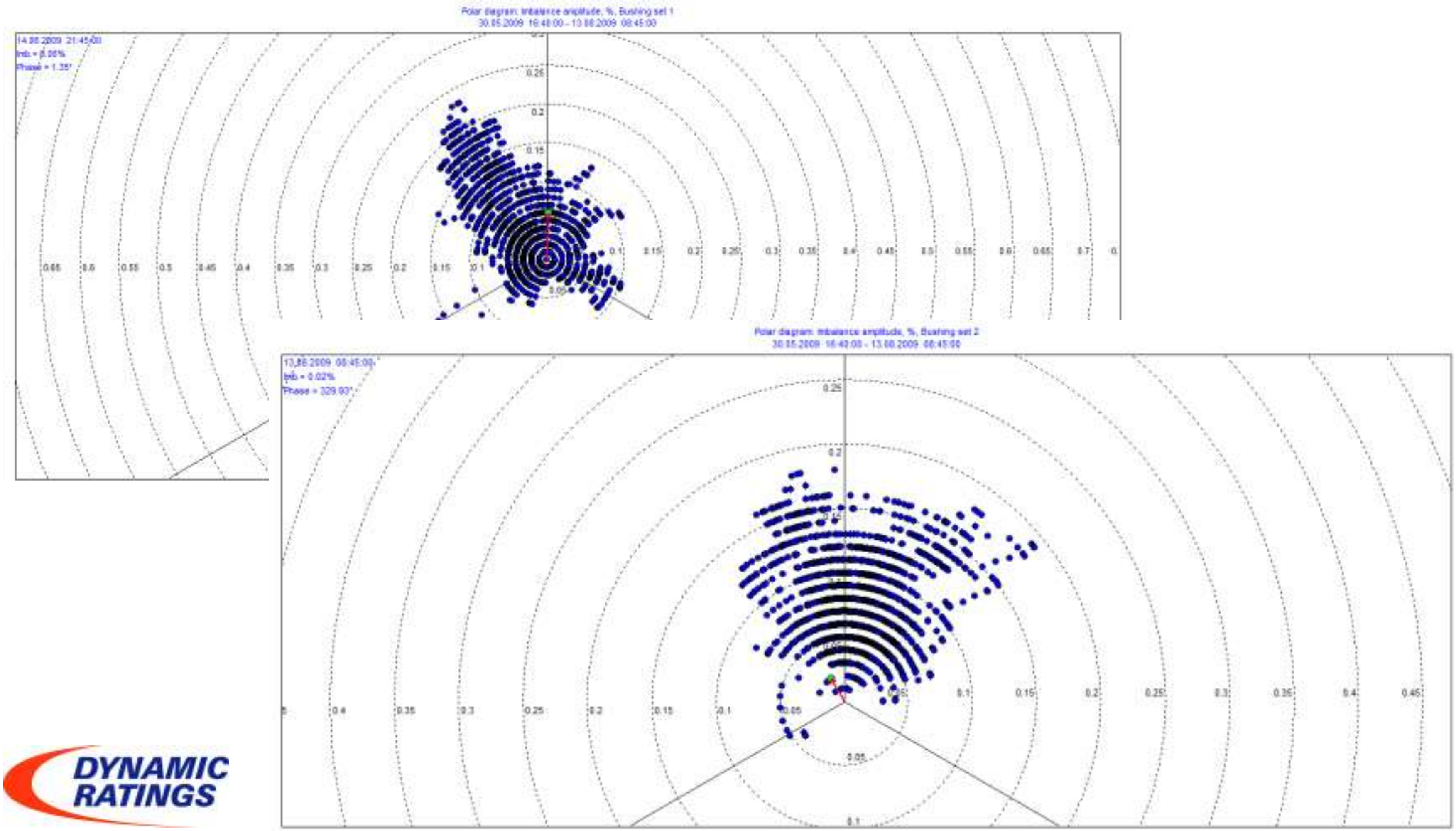
Noise

Bushing Monitoring





Bushing Monitoring



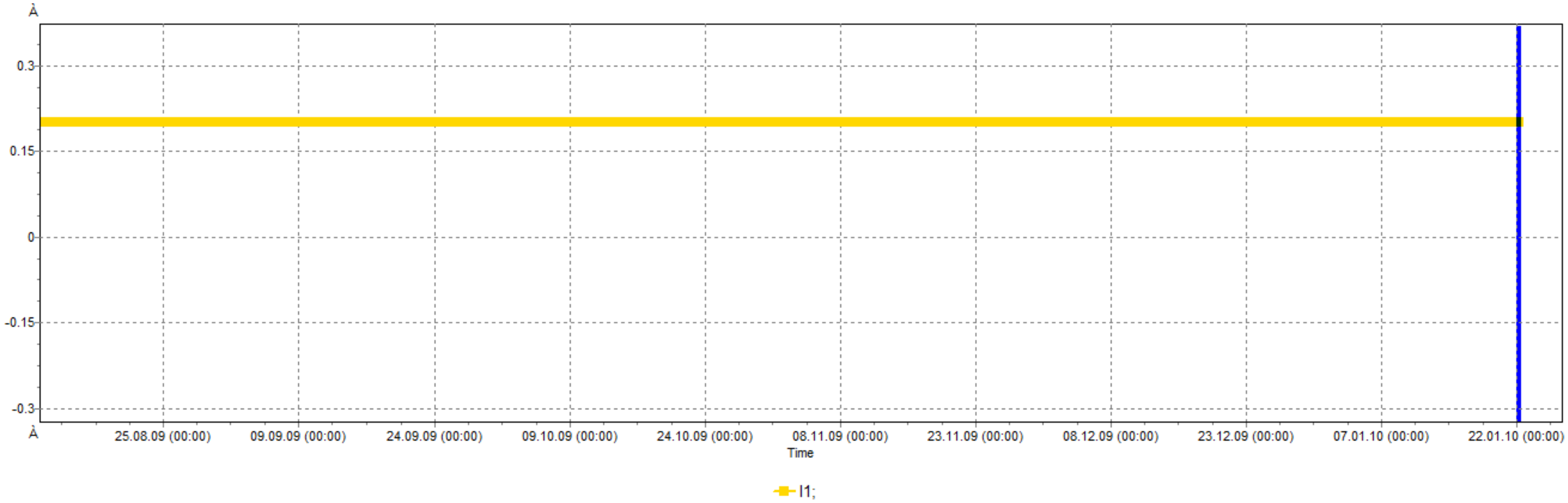
Case 3

- 500 kV – 230 kV - 3 Single Phase Transformers
- 6 Bushing Sensors
- 6 Rogowski Coils
- 4 Acoustic PD sensors per phase
- RFCT on Neutral
- RFCT – Core Ground
- Power Frequency CT On Core Ground

Case 3 Installation

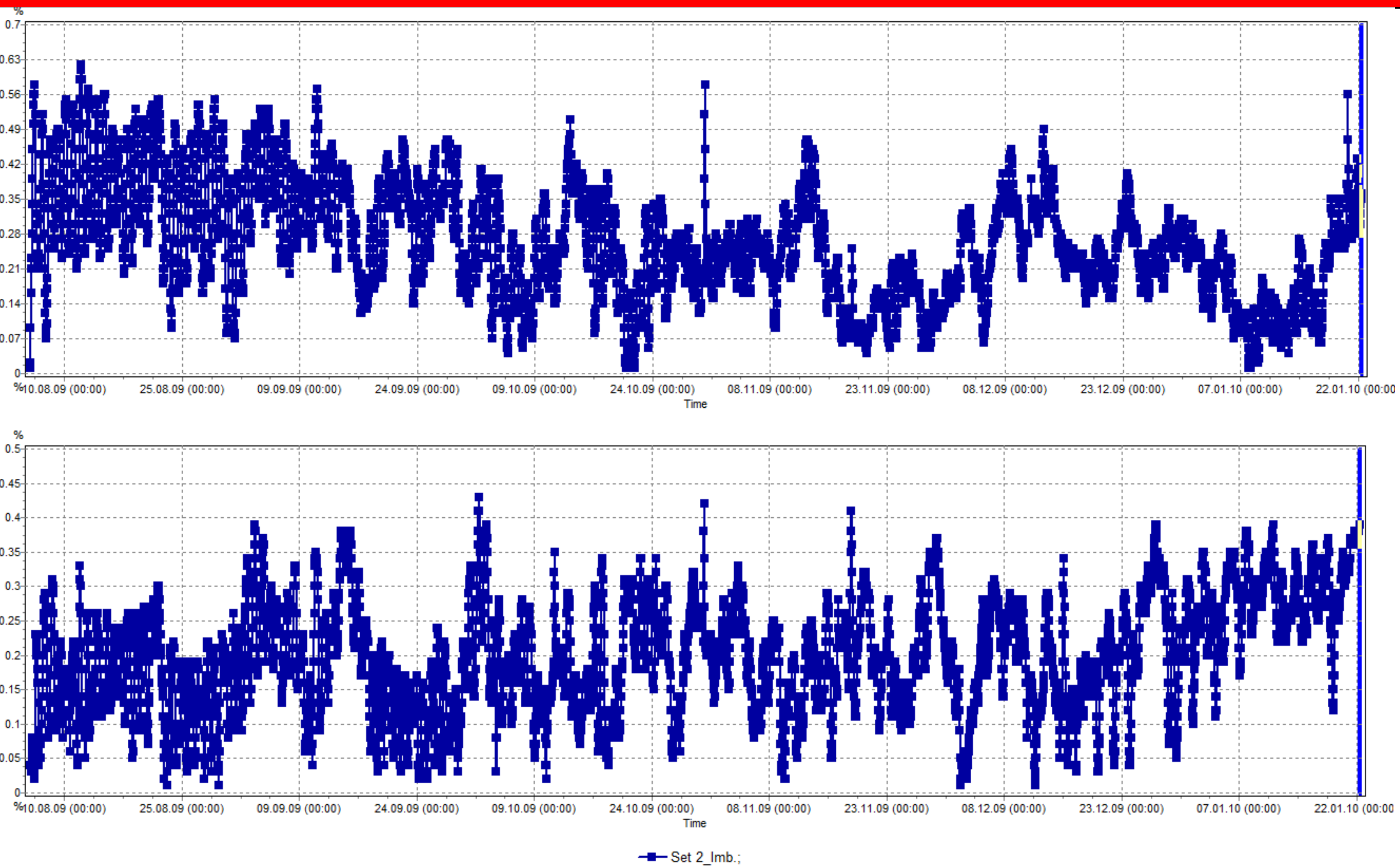
RATINGS

Case 3 – Core Ground Current

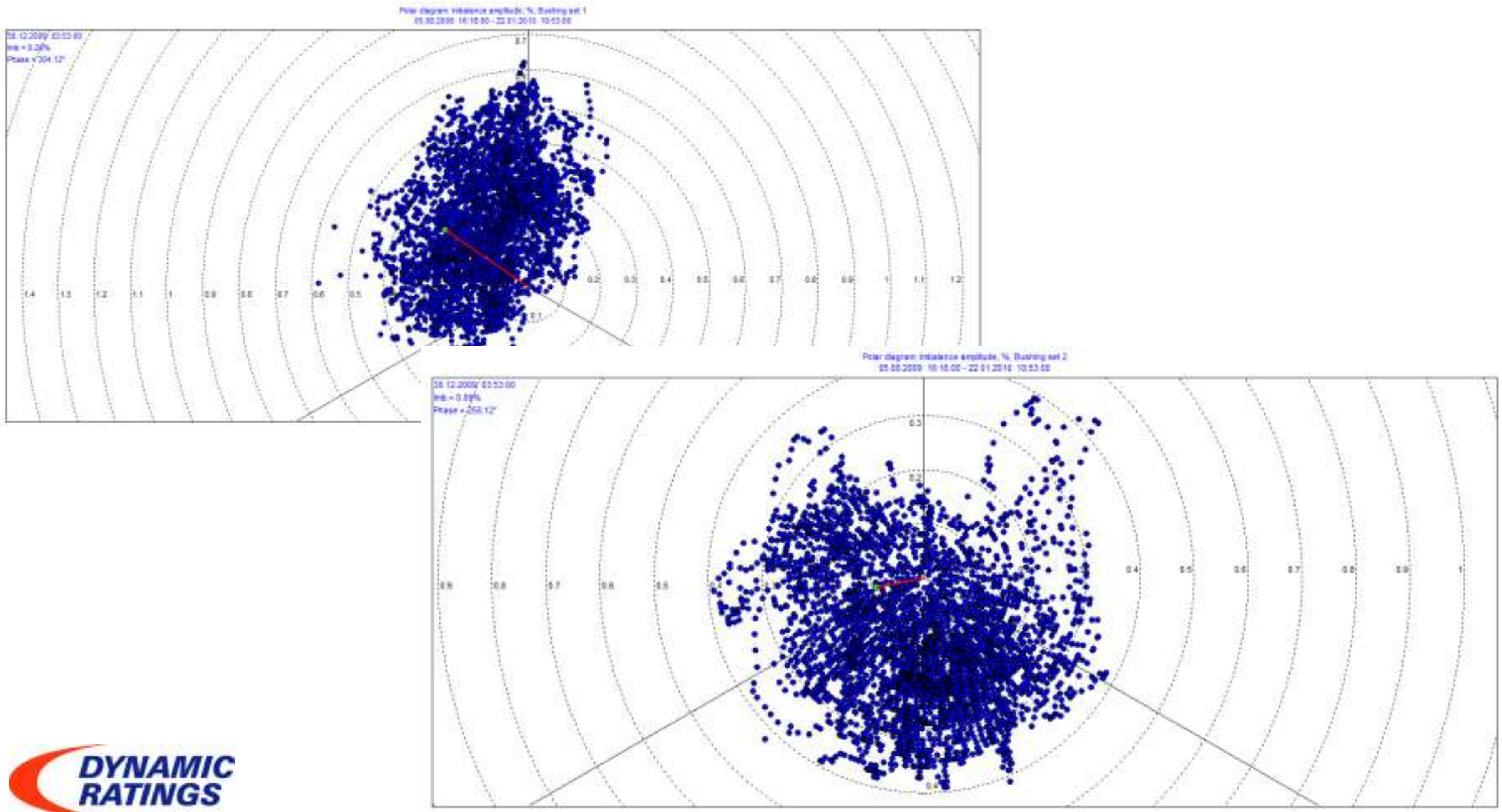


DYNAMIC RATINGS

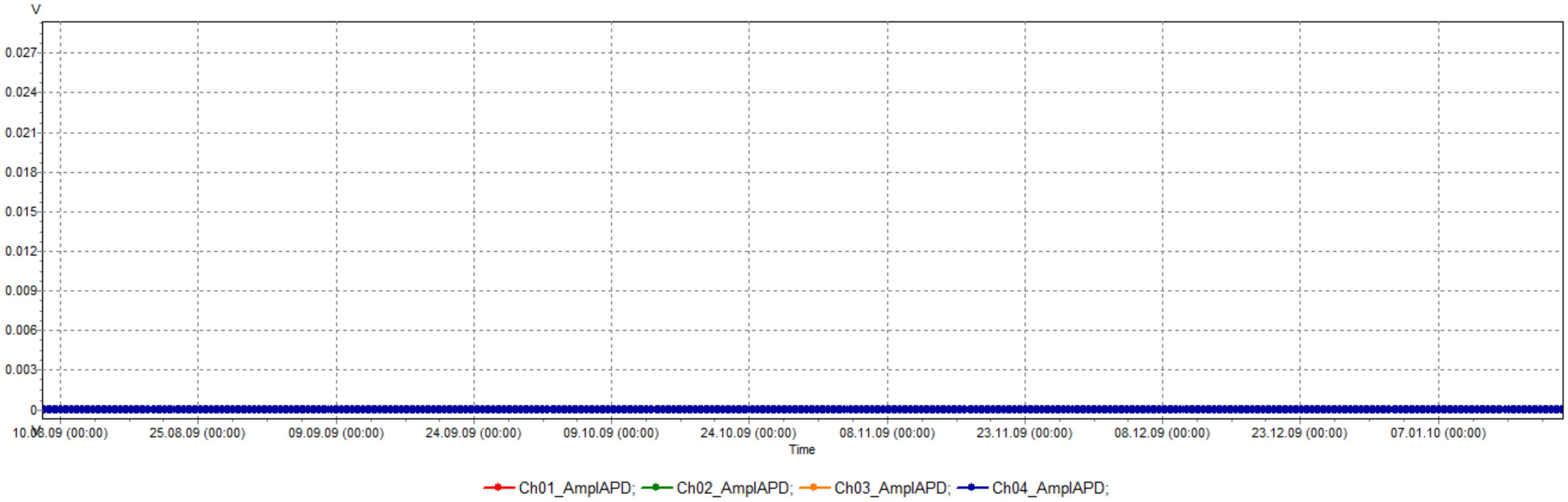
Case 3 Bushing Data



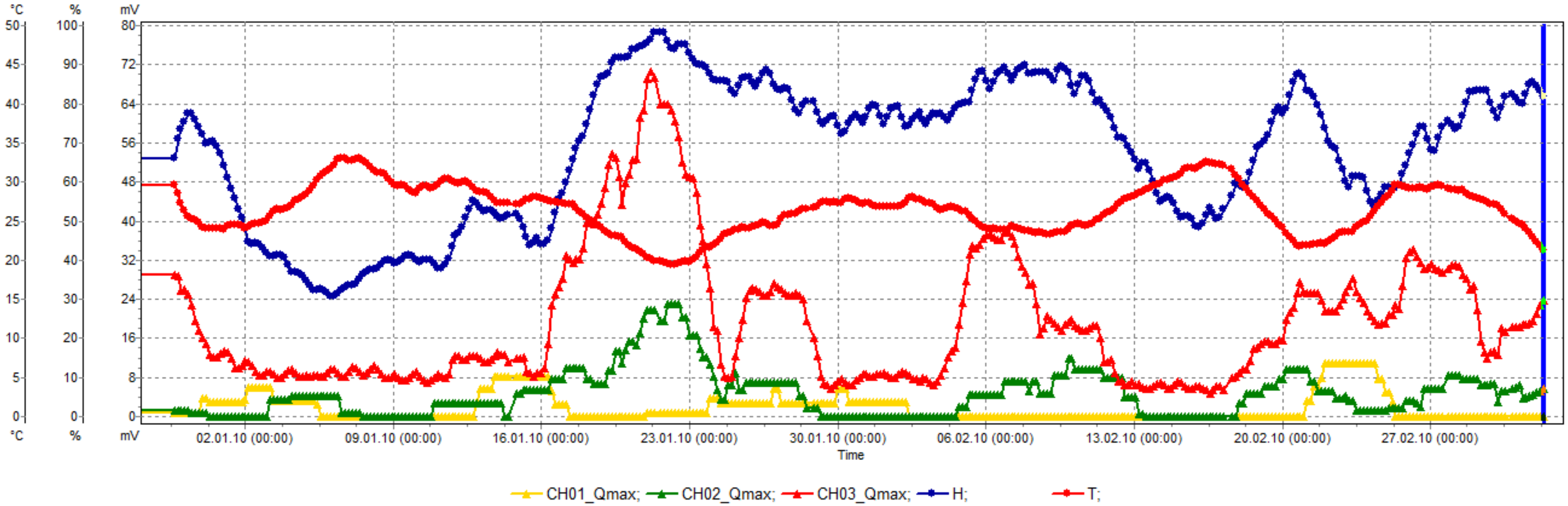
Case 3 Bushing Data



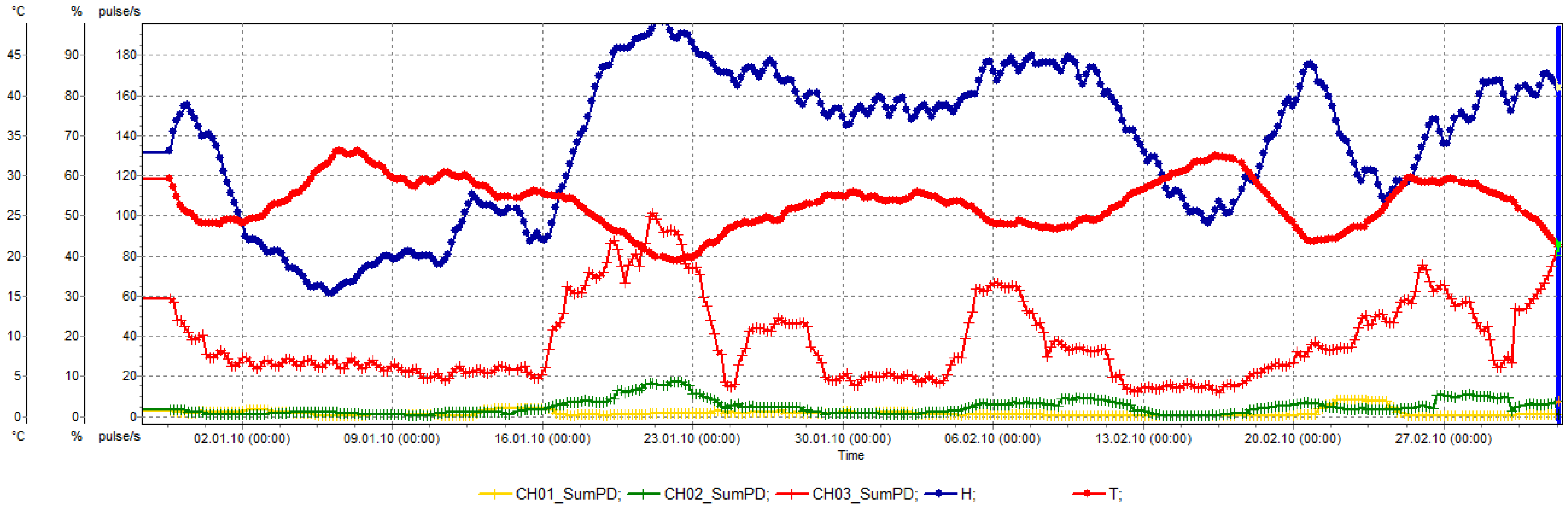
Case 3 Acoustic PD



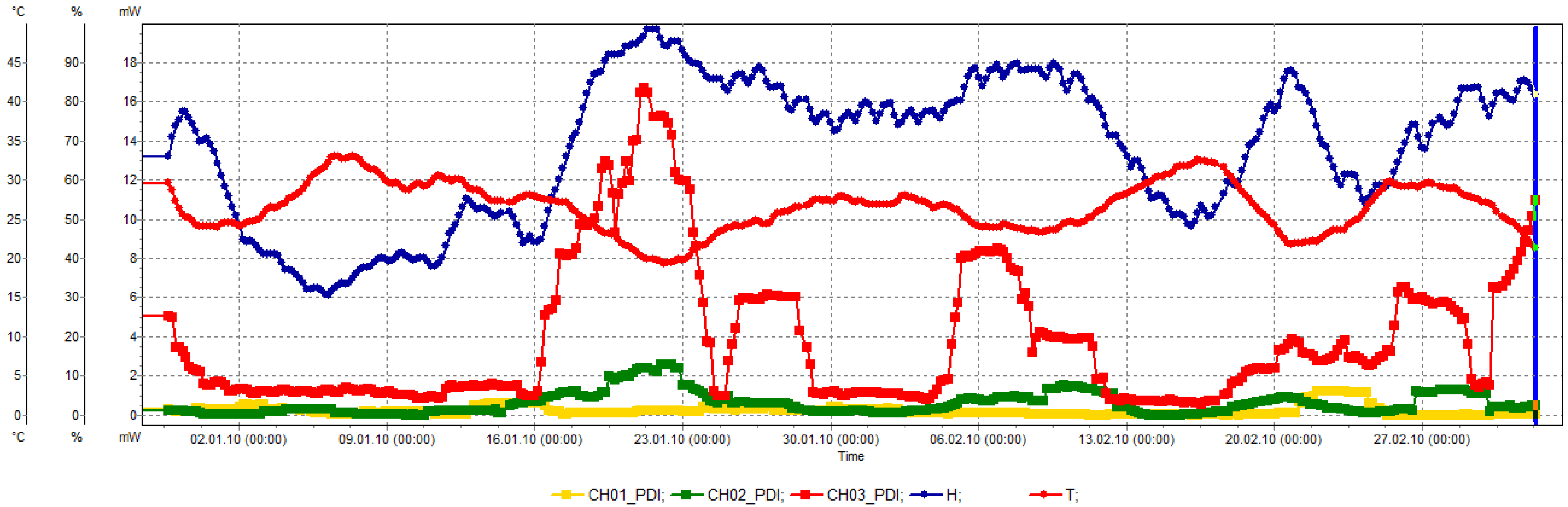
Case 3 Electrical PD



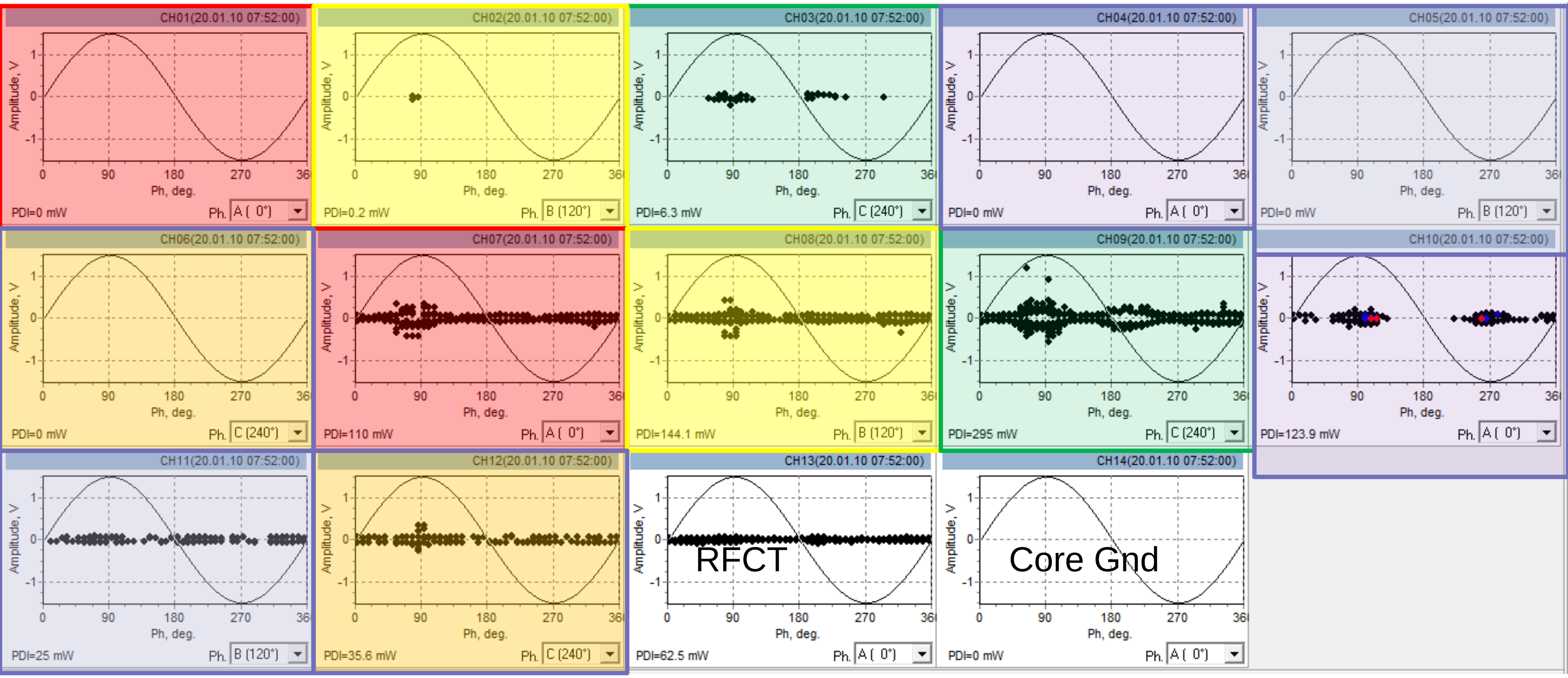
Case 3 Electrical PD



Case 3 Electrical PD



Case 3 Phase Resolved Data

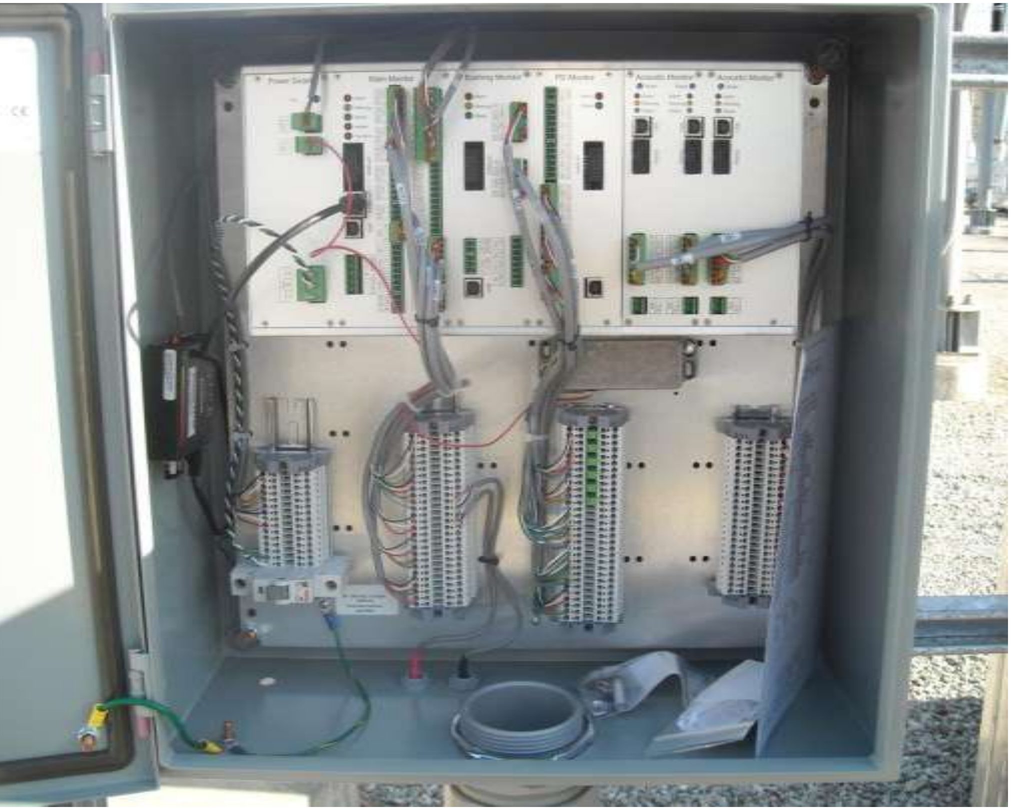


DYNAMIC RATINGS

Substation

DYNAMIC RATINGS

DTM



DYNAMIC RATINGS

BAU and Rogowski Coil

DYNAMIC RATINGS

Core Ground Current and RFCT

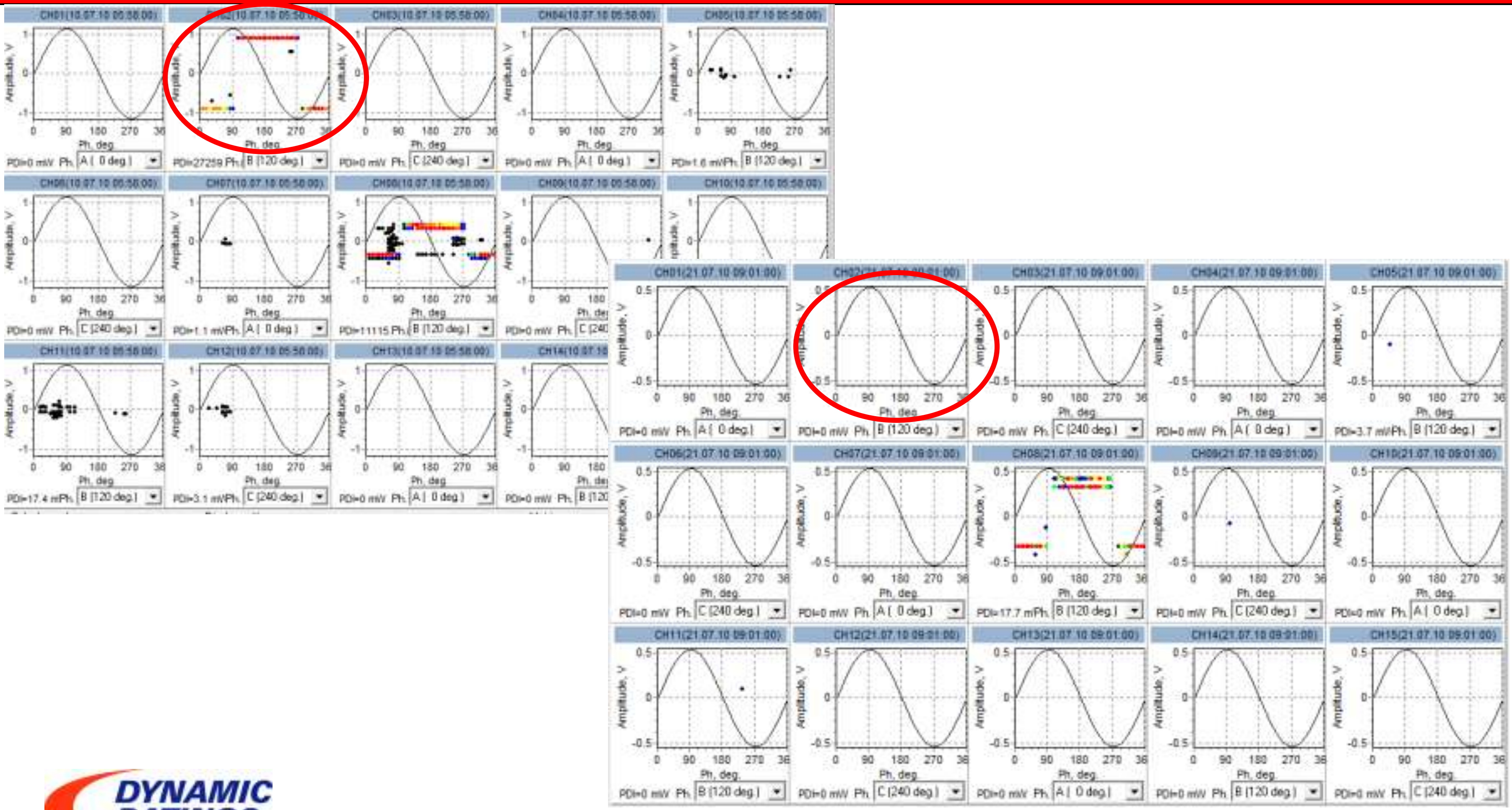
DYNAMIC RATINGS

Top and side Aux. Boxes

Acoustic and Load Current Aux. CT

DYNAMIC RATINGS

Before and After Pulse Polarity Detection Turned On



DYNAMIC RATINGS

Another Recent Install - Indonesia

Another Recent Install

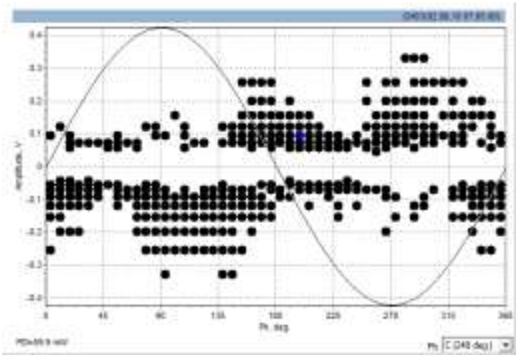
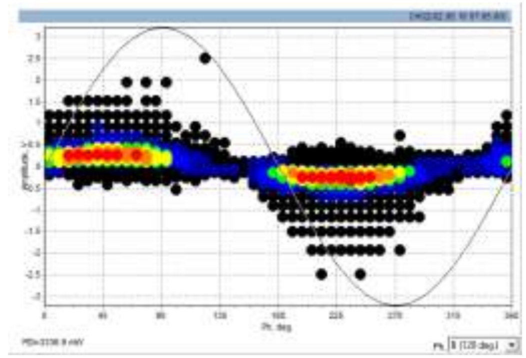
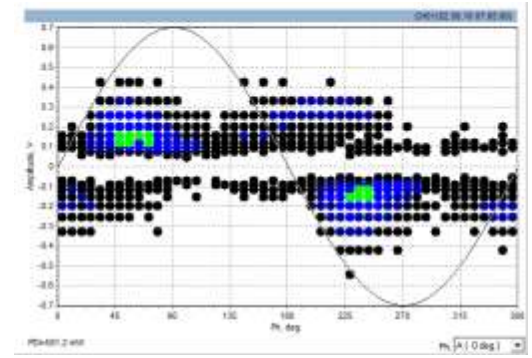
DYNAMIC RATINGS

110 kV HVCT’s

DYNAMIC RATINGS

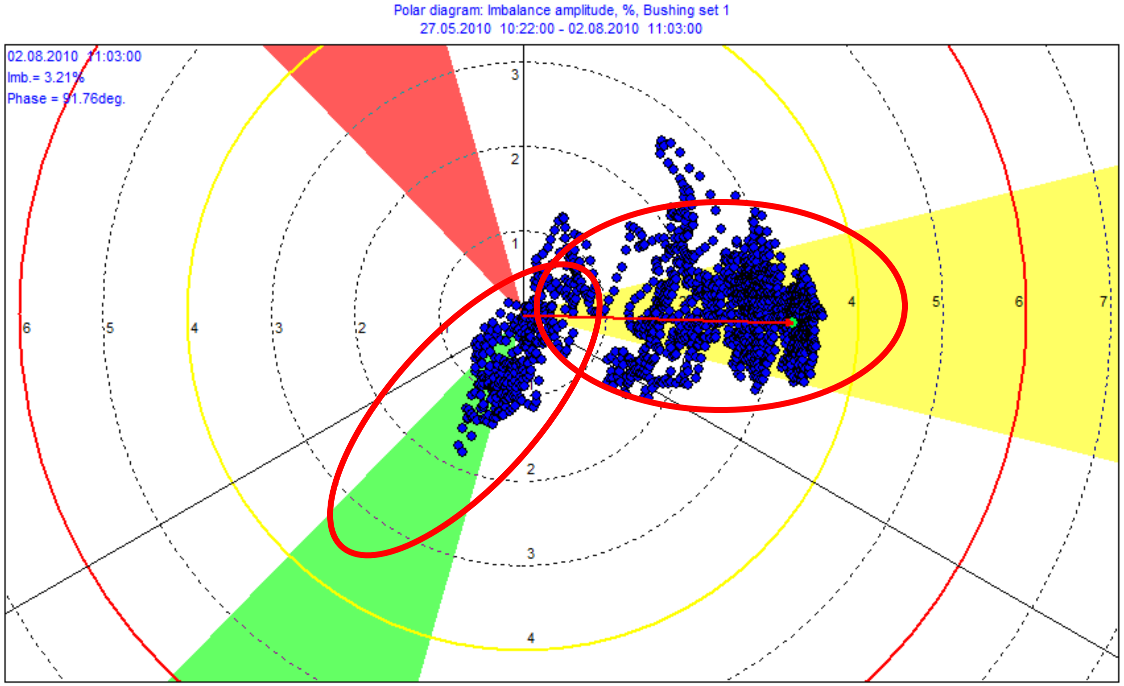
DGA and Tan Δ

Phase	R	Y	B
% PF – 10 kV	.891	12.17	2.05
Capacitance (pF)	639	567	595
Hydrogen	113	19,432	
Methane	5	12,637	
Ethane	3	2,234	
Ethylene	3	21	
Acetylene	1	1	
CO2	401	251	

Bushing Monitoring

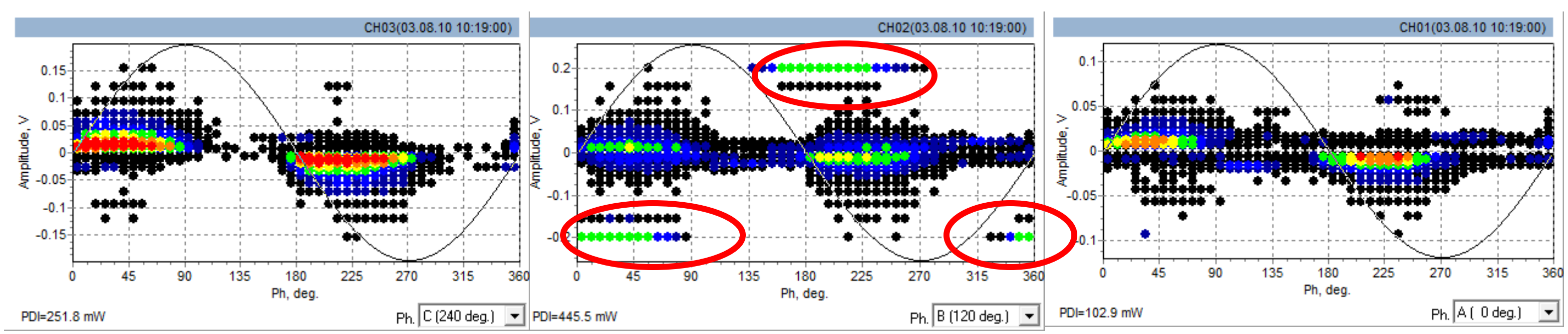
- Can see the Power Factor is changing on two of the bushings



DYNAMIC RATINGS

Second Location

Phase	R	Y	B
% PF – 10 kV	4.041	3.302	2.610
Capacitance (pF)	341	350	329
Hydrogen	12024	18714	15881
Methane	9400	11524	8216
Ethane	7214	2675	1852
Ethylene	20667	224	.01
Acetylene	87	0.1	0.1
CO2	236	260	140



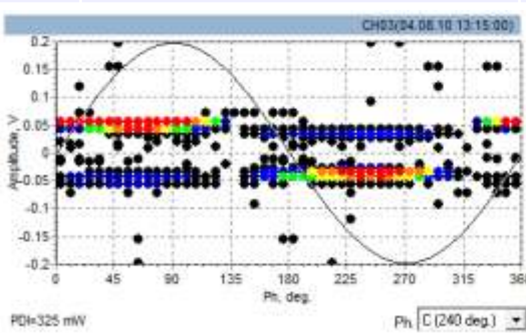
DYNAMIC RATINGS

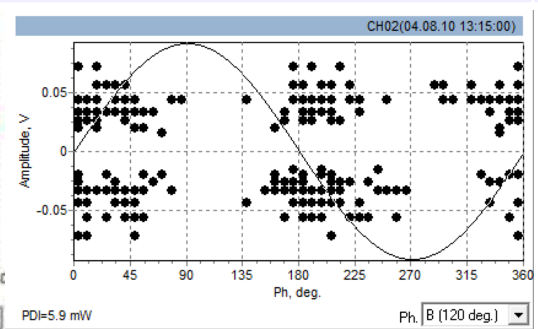
Circled areas are noise – Floating Potentials

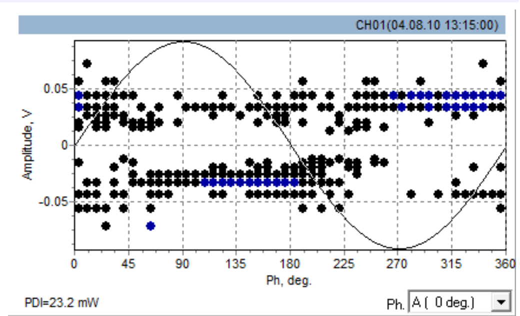
2 hour Period – No bushing monitoring performed

Third Location

Phase	R	Y	B
% PF – 10 kV	31.48	28.33	14.45
Capacitance (pF)	511	485	542
Hydrogen	6	6	4
Methane	6	4	2
Ethane	3	3	1
Ethylene	1	1	1
Acetylene	1	1	1
CO2	668	356	356







DYNAMIC RATINGS

Little to No PD – Mostly Noise

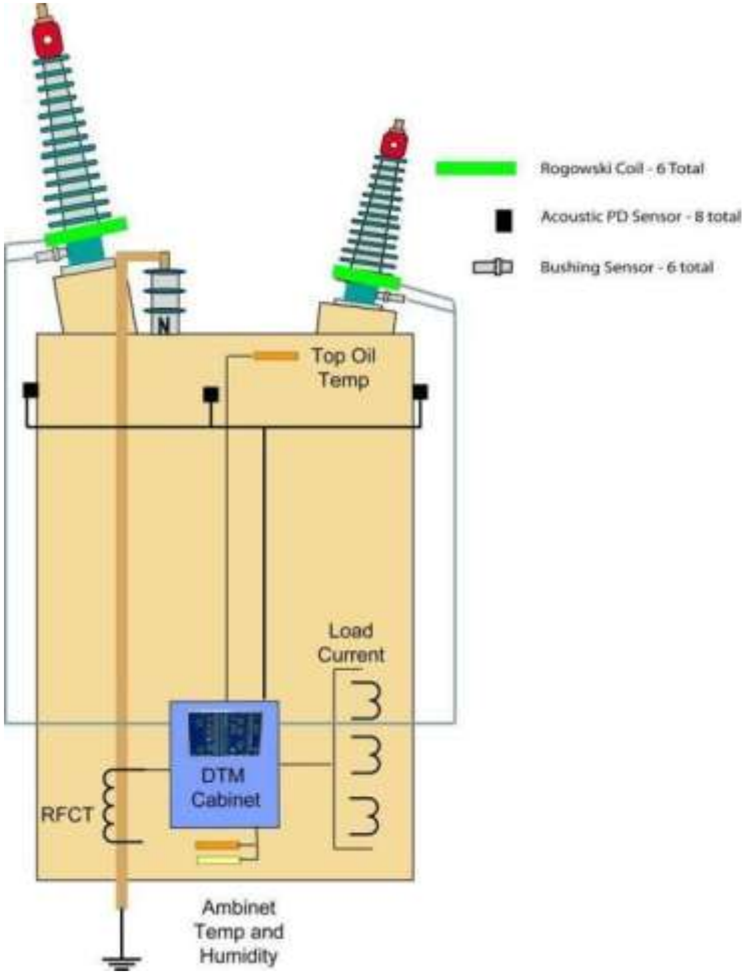
2 hour Period – No bushing monitoring performed

Transformer Applications

- Transmission
- Distribution
- GSU
- Generator / Bus Duct / GSU
  - Only supplier that can offer a single solution

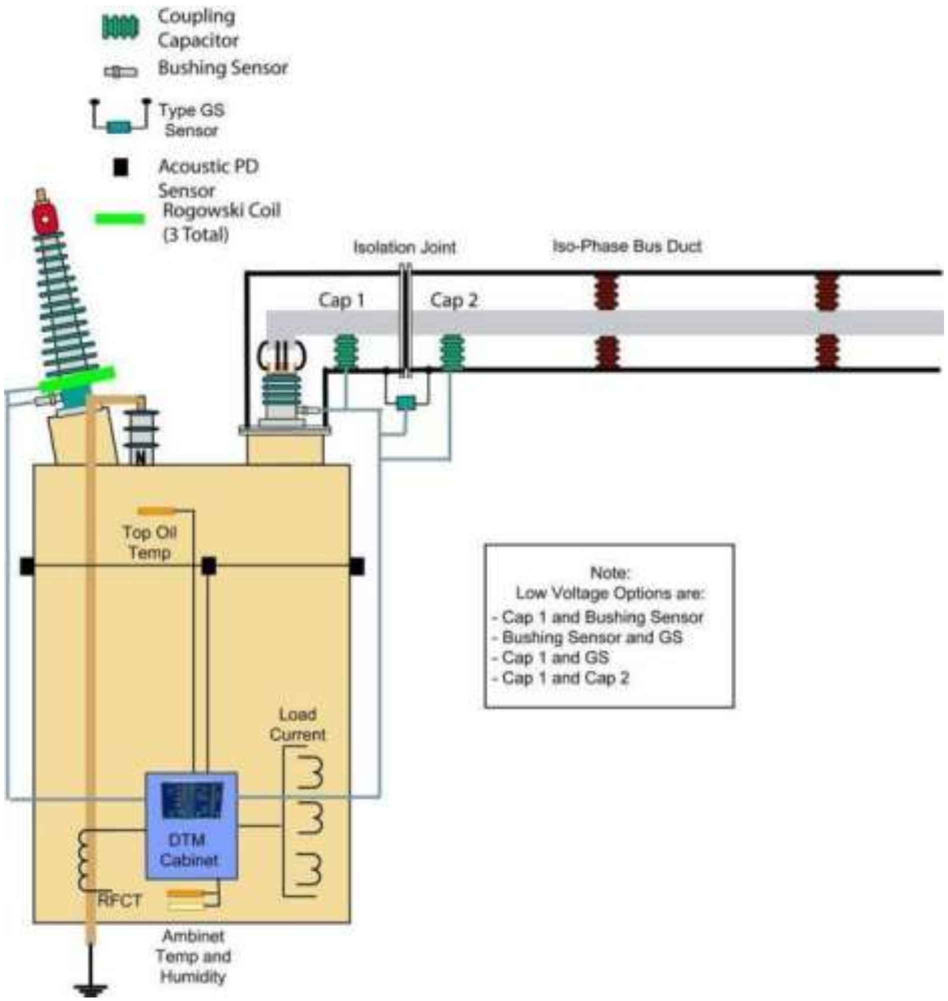
DYNAMIC RATINGS

Transmission Transformer

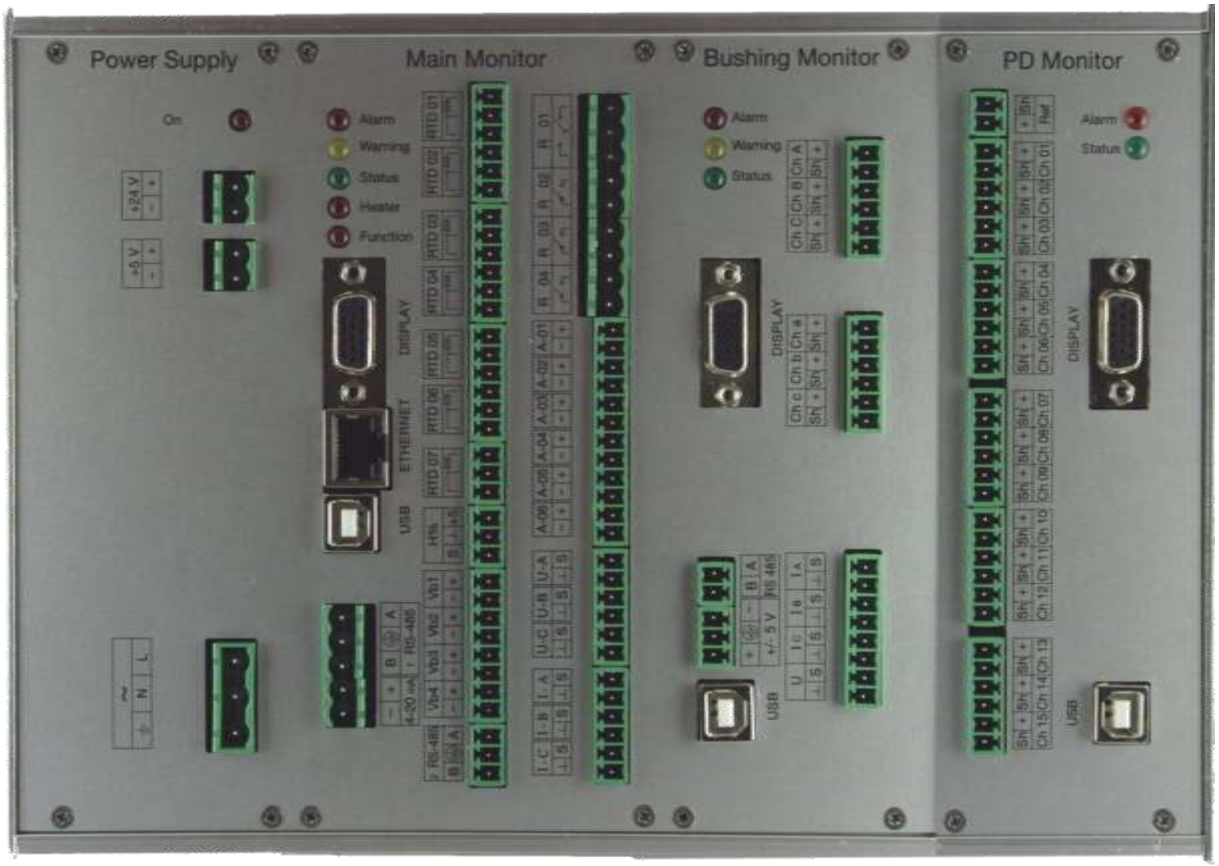


DYNAMIC RATINGS

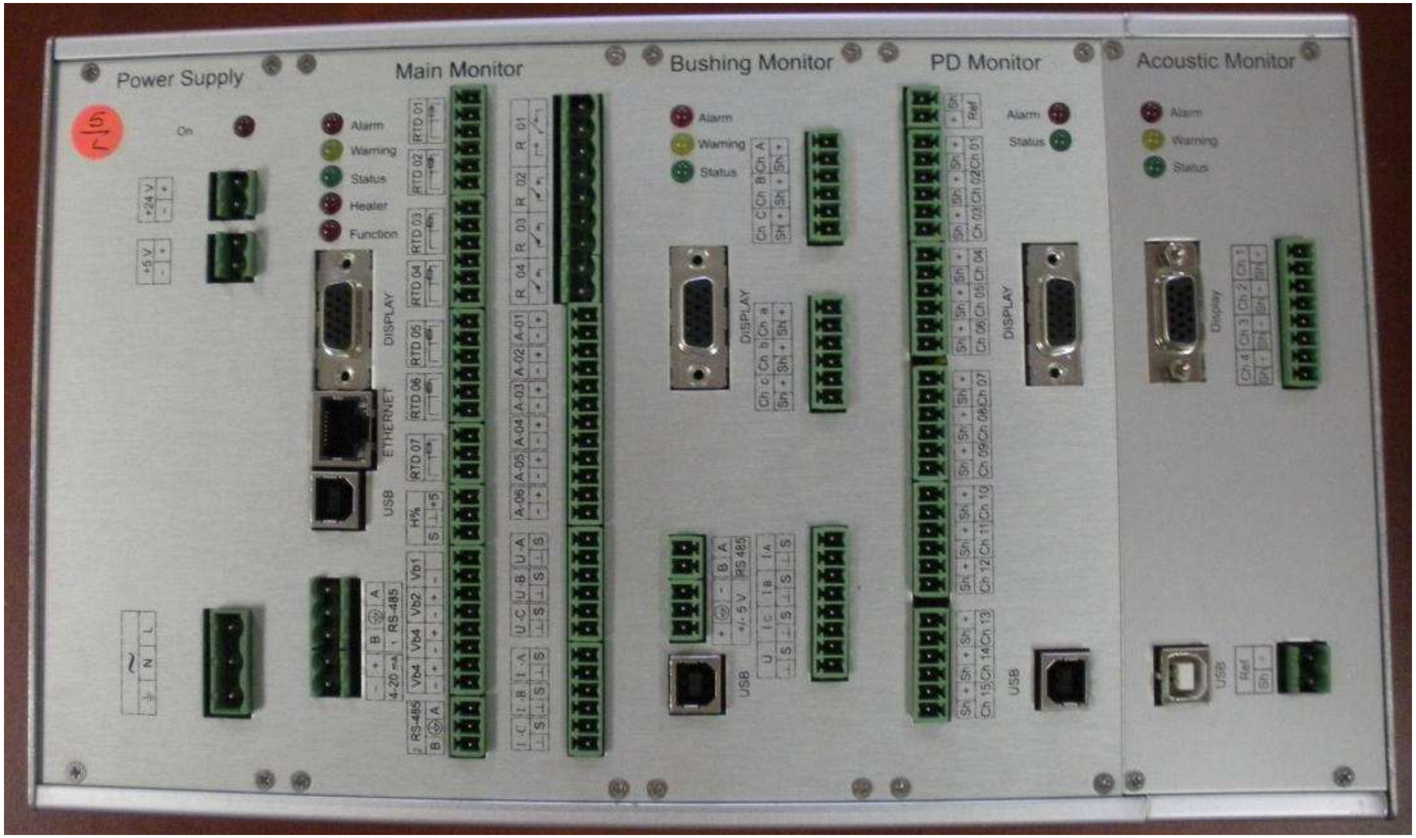
GSU


Coupling Capacitor
Bushing Sensor
Type GS Sensor
Acoustic PD Sensor
Rogowski Coil (3 Total)
Isolation Joint
Iso-Phase Bus Duct
Cap 1
Cap 2
Top Oil Temp
Note:
Low Voltage Options are:
- Cap 1 and Bushing Sensor
- Bushing Sensor and GS
- Cap 1 and GS
- Cap 1 and Cap 2
Load Current
DTM Cabinet
RFCT
Ambinet Temp and Humidity

Diagnostic Transformer Monitor (DTM)



Standalone System With Acoustic PD Module



Integrated Bushing and PD Modules

DYNAMIC RATINGS

http://192.168.227.130/mainFrame.htm

DRMCC

TRANSFORMER ID AND LOCATION:

LOCATION

DATE AND TIME ON SITE: 17-Nov-2009 10:38:56 AM

LOCAL DATE AND TIME: 08-Sep-2009 08:25:05 AM

OVERVIEW | RATING PLATE | ELECTRICAL DATA | TEMPERATURES | LTC & AVR | COOLERS | CONDITION

Aquaoil
Calisto
Hydran
IDD
TrueGas
Vaisala
BHM
PDM
ICM
SPEC
TRANSFIX
SERVERON
Default

Partial Discharge Monitor

Device Status	OK		
Alarm Status	Warning	**Alarm Cause**	Maximum amplitude

Last Measurement: Sep 7, 2009 | 11:41

Channel	pC	Q (mV)	PD Intensity (mW)	Pulse Count (PPS)	Status
1	810	81	74	19187	Active
2	1050	105	81	16450	Active
3	1050	105	84	16455	Active
4	1050	105	83	15791	Active
5	1050	105	80	15594	Active
6	1050	105	70	14424	Active
7	0	0	0	0	InActive
8	0	0	0	0	InActive
9	0	0	0	0	InActive
10	0	0	0	0	InActive
11	0	0	0	0	InActive
12	0	0	0	0	InActive
13	0	0	0	0	InActive
14	0	0	0	0	InActive
15	0	0	0	0	InActive

Temperature | Cooler Fail | Voltage | TC fail | Ancillaries | System

Fans on | Pump on | TC Raise | TC Lower | TCIP | Power on